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MEMORANDUM TO: Theodore R. Quay, Director
Standardization Project Directorate
Division of Reactor Program Management

FROM: Goutam Bagchi, Chief
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SUBJECT: MAJOR SAFETY ISSUES RESULTED IN CIVIL/STRUCTURAL REVIEW - AP600 STANDARD PLANT

The Civil Engineering and Geosciences Branch has completed its reviews of (1) AP600 SSAR Sections 3.7 and 3.8 up to and including Revision 4, (2) samples of design calculations, (3) Westinghouse's submittal related to seismic analysis and structural design and (4) information obtained at design review meetings with Westinghouse. As a result of these reviews, 51 out of 129 open items documented in the AP600 draft safety evaluation report (DSER) are considered closed. Among the remaining 78 open items as summarized in Attachment 1, many are considered technically resolved, and Westinghouse is required to revise the SSAR for the final resolution of these items. However, there are five issues that are considered major issues (Attachment 2), and the resolution of these issues will affect the final design of AP600 seismic Category I structures, systems and components. We realize that the review of AP600 design has been postponed and the schedule for resuming this review is unknown. Therefore, we are documenting the status of our reviews in these areas for the record and for use in future reviews.

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Attachment 1

Unresolved DSER Open Items

As a result of the staff's review of (1) AP600 SSAR Sections 3.7 and 3.8 up to and including Revision 4, (2) Westinghouse's letter submittal related to the civil structural analysis and design and (3) information obtained at design review meetings with Westinghouse, the following DSER open items remain open:

	DSER Open Item No.	Description of Open Items
1	OI 3.7-1	Classification of structures adjacent to nuclear island structures
2	OI 3.7.1-2	20 percent damping for cable tray seismic analysis
3	OI 3.7.1-4	Adequacy of 6 ft foundation mat
4	OI 3.7.1-5	Building dimensions used for seismic analyses
5	OI 3.7.1.1-1	SSAR commitment for the site specific ground motion to satisfy response spectrum and PSDF enveloping criteria
6	OI 3.7.2.1-4	Revise the SSAR as described in the draft of SSAR Section 3.7.2, Revision 4
7	OI 3.7.2.3-3	Demonstrate adequacy of equivalent lumped mass model whose 2nd modal frequency is much higher than 2nd frequency of detailed model
8	OI 3.7.2.3-6	Westinghouse to provide (1) figures of rigid links in connecting stick model and basemat and (2) criteria used for establishing relative for air baffle design in the SSAR
9	OI 3.7.2.3-7	Westinghouse to describe how 3D shell model constructed from 3D finite model
10	OI 3.7.2.4-5	Incorporation of the use of the Idriss 1990 soil strain degradation model in the SSAR
11	OI 3.7.2.4-7	Design of embedded walls and pounding between buildings due to structure-soil-structure interaction
12	OI 3.7.2.4-8	Documentation of using a parabolic variation of soil profile in the SSAR
13	OI 3.7.2.4-9	W to make correction regarding the use of the SHAKE computer code for computing strain compatible Poisson's ratio in the SSAR

14	OI 3.7.2.4-12	Adequacy of using three design site conditions for developing seismic response envelopes
15	OI 3.7.2.6-1	Inclusion of a list of analysis cases showing how and where each of the three combination techniques was applied in the SSAR
16	OI 3.7.2.7-1	W to revise the SSAR to show where each of the three combination techniques for closely spaced modes was applied
17	OI 3.7.2.8-2	Design of buildings adjacent to nuclear island structures to criteria for seismic Category II structures
18	OI 3.7.2.8-3	Classification of radwaste building
19	OI 3.7.2.8-4	Seismic Category II structures which are designed for load factors will not fail under an SSE
20	OI 3.7.2.8-5	Westinghouse's design techniques used for non-seismic Category structures
21	OI 3.7.2.8-7	Seismic Category II structures to withstand 0.5g without collapse
22	OI 3.7.2.12-1	Comparison of seismic responses by response spectrum analysis method and time history analysis method
23	OI 3.7.2.16-1	SSAR commitment of performing seismic reconciliation analysis
24	OI 3.7.3.2-2	Justification of using equivalent static method for analyzing subsystems
25	OI 3.8.2.2-1	Use of 1989 Addenda to ASME Code
26	OI 3.8.2 3-1	Loads and load combinations for vessel design
27	OI 3.8.2.4-3	Demonstration of equivalent static analysis results bound local stresses by dynamic analysis
28	OI 3.8.2.4-8	Validation of CB&I computer code E0781B
29	OI 3.8.3.1-1	Connections between M wall modules, and between M modules and other types of modules
30	OI 3.8.3.1-2	Impact effect of internal structures on containment shell due to uplifting
31	OI 3.8.3.2-1	Incorporation of staff's position on the use of AISC N690 in SSAR Section 3.8.3
32	OI 3.8.3.2-4	Correction of SSAR to include Subsection 3.8.3.2.2.1
33	OI 3.8.3.2-5	Westinghouse to justify applicability of AISC N690 and ACI 349 for design of modules

34	OI 3.8.3.3-1	Definition of construction loads for modules
35	OI 3.8.3.3-2	Hydrostatic pressure against steel wall of M modules due to concrete pour
36	OI 3.8.3.3-3	Consideration of (1) combined loads of ADS actuation and SSE for IRWST design, and (2) thermal loads for steel frame design
37	OI 3.8.3.4-3	Adequacy of module design based on assumption of composite section
38	OI 3.8.3.4-4	To consider steel wall for calculating moment of inertia of modules outside containment
39	OI 3.8.3.4-5	Concern of using SSAR equations for computing equivalent properties of isotropic shell model
40	OI 3.8.3.4-6	Seismic modeling of containment internal structures
41	OI 3.8.3.4-8	Concrete integrity due to steel wall buckling
42	OI 3.8.3.4-9	Interaction effect of vertical compression stresses with other perpendicular in-plane horizontal stresses and shear stress
43	OI 3.8.3.4-10	Consideration of biaxial bending in combined stress equations of Section 3A.3.1.3
44	OI 3.8.3.4-11	Design details of module connections
45	OI 3.8.3.4-12	Westinghouse to provide design summary report for review
46	OI 3.8.3.4-13	Staff audit of design calculations of modular construction
47	OI 3.8.3.5-1	Inclusion of supplemental acceptance criteria in SSAR Section 3.8.3.5
48	OI 3.8.3.5-2	Distortion of modules due to handling, fabrication, shipping, storage, and/or fit-up
49	OI 3.8.3.6-1	Description of modular construction techniques in SSAR
50	OI 3.8.3.6-2	Placement and curing of concrete inside M modules
51	OI 3.8.4-1	Inclusion of geometrical properties in SSAR
52	OI 3.8.4.1-3	Inclusion of description and design details of modules in aux building
53	OI 3.8.4.2-2	Adequacy of using ACI-349-90 Code
54	OI 3.8.4.2-4	Adequacy of using Appendix B to ACI-349 Code for design

55	OI 3.8.4.3-1	Consideration of live in dynamic models
56	OI 3.8.4.4-1	SSAR to describe specific design load combinations
57	OI 3.8.4.4-2	Westinghouse to provide design calculations of shield building and passive cooling water storage tank for review
58	OI 3.8.4.4-4	Design of embedded walls against soil pressure
59	OI 3.8.4.4-6	Analysis procedures and design details of spent fuel pool, fuel transfer canal, and new fuel storage area
60	OI 3.8.4.4-7	Inclusion of IRWST and air baffle in component list
61	OI 3.8.4.5-1	Criteria description for modules with different configurations and applications
62	OI 3.8.4.5-2	Quality control requirements for modules
63	OI 3.8.5-1	Dimensions of foundation mats
64	OI 3.8.5-2	Use of ACI-349-90 Code for design of foundation mat
65	OI 3.8.5-3	Combination of accident pressure with other design loads for foundation design
66	OI 3.8.5-4	Include buoyancy effect in load combinations of SSAR Table 3.8.5-1
67	OI 3.8.5-5	Inclusion of vertical soil springs in foundation design
68	OI 3.8.5-6	Basis of using only two combined load cases for basemat up-lift analyses
69	OI 3.8.5-8	Validation of INITEC's in-house codes
70	OI 3.8.5-9	Perform simplified analysis, using ACI 336 procedures to verify foundation design adequacy
71	OI 3.8.5-10	Basis to demonstrate design adequacy in coping with unevenly distributed construction loads
72	OI 3.8.5-11	Effects of (1) local soft spots of soil foundation, (2) non-uniform soil springs for mat design and (3) soil stiffness corresponding to other soil conditions
73	OI 3.8.5-12	Seismic shears and moments due to out-of-phase vibration between shield building, cont vessel and internal structure
74	OI 3.8.5-17	Inclusion of construction loads and sequence of these loads in mat design
75	OI 3.8.5-18	Overhangs at end of foundation mat
76	OI 3.8.5-19	Impact effect between mat and rock

77	OI 3.8.5-20	Validation of INITEC's references used in mat design
78	OI 3.8.5-21	Design calculations of foundation mat

Attachment 2

Major Issues in Civil/Structural Area
Resulted From AP600 Review

Discussed below are five major issues that need to be resolved by Westinghouse for allowing the staff to complete its review:

A. Seismic Model of Nuclear Island Structures

Westinghouse used a multi-stick (Containment vessel, containment internal structures and shield/auxiliary building) lumped-mass model for the seismic analysis of nuclear island structures. This multi-stick lumped-mass model was developed based on a three dimensional (3D) finite element model of these building structures. However, the lumped-mass stick model of the shield building roof structure was developed by Westinghouse's consultant ANSALDO, an Italian engineering company. From its review of the seismic analysis and design calculations of nuclear island structures, the staff found that the seismic member forces (shear forces, axial forces and bending moments) of the shield building roof structure calculated using a combined roof stick model and the finite element model of remaining structures are significantly different from those calculated by a complete stick model. For some member forces of the roof structure, the difference is as high as one hundred percent. In general, a finite element model can simulate the actual behavior of a structure much more closely than a lumped-mass stick model. Based on this review finding, the staff concludes that the 3D lumped-mass multi-stick model used for generating design information (member forces and floor response spectra) for the design of safety related structures, systems and components is not acceptable, because the seismic responses based on the 3D lumped-mass multi-stick model of nuclear island structures used by Westinghouse can not represent the actual behavior of the structure during an earthquake and these analysis results may lead to an unconservative design. Westinghouse should ensure that every step of the modeling process meets the guideline of SRP Section 3.7.2 and that the overall model (3D lumped-mass stick model) should simulate the true behavior of structures under an earthquake.

B. Seismic Soil-Structure Interaction Analyses

1. Adequacy of Using Only Three Site Conditions for the Design of AP600 standard plants

   As committed in the SSAR, Westinghouse performed a set of 3D seismic soil-structure interaction analyses and used these results for the following:

   A. to generate floor response spectrum envelope for the design of subsystems (equipment and components), and

   B. to calculate seismic member forces (axial forces, shear forces and bending moments) for the design of nuclear island structures.

The 3D seismic analyses performed by Westinghouse adopted only three site conditions that were selected on the basis of two dimensional (2D) parametric studies. A large number of site parameters were subjectively considered, but not all significant combinations of site parameters were analyzed. As such, the staff raised a concern whether the envelope of analysis results from the limited number of 3D analysis cases reasonably cover the broad range of potential site-conditions for which the AP600 standard plant is to be designed. An adequate resolution of this concern has been difficult because the 2D parametric analyses could not systematically narrow down the number of parameters and combination of parameters to those that should be used in the final 3D design basis analysis cases. Instead, many possible parameter combinations were eliminated.

In order to strengthen the basis of its conclusion for the seismic review of the AP600 standard plant design, the staff performed a confirmatory SSI analysis. In this confirmatory analysis, the site condition was chosen to be the upper bound of the soft rock site used by Westinghouse with the shear wave velocity of the supporting material equal to 1066.8 m/sec (3,500 ft/sec). This site condition is not one of site conditions considered in the AP600 standard plant design. A comparison shows that results (floor response spectra) obtained from the confirmatory analysis exceed the seismic design envelope floor response spectra at several locations in the nuclear island structures. There is an indication that the three design site conditions documented in early SSAR amendments might not adequately cover the spectrum of potential sites in the United States, and the plant subsystems (piping and components) will be under-designed if a AP600 plant is located at one site with a shear wave velocity of the supporting material equal to 1,066.8 m/sec (3,500 ft/sec). From this finding, the staff concludes that the design of the AP600 nuclear island structures including subsystems based on the three site conditions documented in the SSAR is not acceptable. Westinghouse should consider to use additional site conditions in the design of AP600 standard plant.

2. Adequacy of Design Loads for Embedded Outside Walls

In the design of peripheral embedded walls of nuclear island structures, the SSAR states that the embedded exterior walls of the nuclear island structures are designed to resist the worst case lateral earth pressure loads. However, during the design review meetings, the staff found that (1) the soil pressure used for the design of walls was much lower than the soil passive pressure used for the NI sliding analysis, and (2) the dynamic soil pressure due to the structure-to-structure interaction effects from the adjacent structures (turbine building, annex buildings and radwaste building) was not included in the wall design. These findings imply that the lateral earth pressure loads used for the design are not the worst case. Therefore, the design of the peripheral walls of the nuclear island structures not on the conservative side and is not acceptable. In addition, in order to resist the high shear stress due to the external earth pressure (both static and dynamic), Westinghouse applied heavy shear reinforcement at locations such as the junction between walls and foundation mat. With relatively small thickness of walls (the wall thickness at junction with the foundation mat is 0.91 m [3 ft]), the congestion of reinforcement and deficiency of workmanship during construction at these locations may cause reduction of shear resistance of walls. Westinghouse should consider these concerns in the final design of these walls.

3. Consideration of Shallow Soil Site

As committed in SSAR Section 3.7.1.1, Westinghouse defined the input ground motion (design ground response spectra and the associated synthetic acceleration ground motion time histories) at the plant finished grade in the free field. Using SRP guidelines, to define the design ground motion at plant finished grade in the free field is acceptable in calculating the seismic responses (both structural member forces and floor response spectra) for the plant structures founded on a uniform site such as deep soil and rock sites. However, for a shallow soil site, the input ground motion should be defined at hypothetical rock outcrop as guided by Section 3.7.1 of the SRP. In general, a shallow soil site can be defined as a site condition with shear wave velocity of the soil layer equal to or lower than 304.8 m/sec (1000 ft/sec) and the depth of soil layer (the distance from the finished grade to the bedrock) equal to or smaller than 30.48 m (100 ft). Although it is specified in Table 2-1 of and Appendix 2a to the SSAR that the minimum shear wave velocity and soil layer depth are 304.8 m/sec (1000 ft/sec) and 30.48 m (100 ft), respectively for the AP600 design, the shallow soil site, as defined, should be clearly excluded from the license application of the AP600 standard plant.

4. The 60 Percent Limitation of Ground Motion at Foundation Level in the Free Field

SRP Section 3.7.2.II.4.c indicates that when the variation of ground motion (amplitude and frequency content) at depth of partially embedded structures is considered in the SSI analysis of safety related structures, the spectral amplitude of the acceleration response spectra at foundation level in the free field shall not be less than 60 percent of the corresponding design response spectra at the finished grade in the free field. This SRP section also indicates that the 60 percent limitation (or guideline) may be satisfied by considering the envelope of the three response spectra at the foundation level in the free field corresponding to the three soil cases considered. If the SSI analysis does not include consideration of the rotational components of ground motion at the depth of interest, no reduction of ground motion is permitted.

In previous years, when simplified SSI analyses were performed (analyses based on constant soil spring and dash pot with lumped-mass stick structural model), the input ground motion (design ground response spectra or ground motion time histories) was applied directly at the foundation of structural model and no reduction of ground motion with embedment depth allowed. As the analysis methods improved, the concern for allowing reductions of ground motion had as much to do with uncertainties in the SSI analyses as well as in specifying the free-field ground motion with depth. With current analysis method and computer software such as the SASSI computer code, the concern of rotational components of ground motion at depth is no longer an issue and certain reduction of motion with embedment depth in the free field is allowed. The latest version of SRP Section 3.7.2.4 provides guideline that the spectral amplitude of the acceleration response spectra at foundation level in the free field shall not be less than 60 percent of the corresponding design response spectra at the finished grade in the free field. This SRP section also states that when variation in soil properties are considered, the 60 percent limitation may be satisfied using an envelope of the three response spectra corresponding to the three soil column properties. In response to DSER Open Item 3.7.2.4-1, Westinghouse demonstrated that the envelope of calculated response spectra corresponding to the three design site conditions met the 60% guideline of SRP Section 3.7.2.II.4. On this basis, the staff stated in the draft FSER that Westinghouse's demonstration meets the guideline of SRP Section 3.7.2.II.4.c.

However, the results from the staff consultant's evaluation of DOE facilities indicate that by uniformly changing the shear modulus of the soil column by a constant factor, both the response spectra at the foundation level as well as the SSI frequencies are all proportional to the soil shear moduli. Therefore, if the response of structures is "in the valley" (in the frequency range of deamplification) of the free field motion for the case of lower bound soil properties, these structural responses will always be in that valley as the soil column uniformly stiffened, because all the soil parameters that control the structural responses are proportional to the soil shear modulus. This finding implies that to satisfy the 60 percent limitation of ground motion at the foundation level by demonstrating the envelope of calculated response spectra corresponding to the three design site conditions met the 60 percent guideline may lead to an unconservative seismic structural response calculation for those cases where SSI effects become important, i.e., the critical response frequencies are controlled by the SSI frequencies. On the basis of this finding, the staff concludes that, in order to ensure an appropriate seismic design of nuclear island structures, Westinghouse should demonstrate that the motion at the foundation level in the free field obtained from the input design ground motion meets the guideline of SRP Section 3.7.2.II.4.c (i.e., the 60 percent limitation).

C. Analysis and Design of Nuclear Island Foundation Mat

As described in Sections 3.7.1 and 3.8.5 of early SSAR amendments, the nuclear island foundation mat thickness is 1.83 m (6 ft) in the auxiliary building area. Based on the review, several errors in the deign calculation of the foundation mat were found over 18 months ago, but satisfactory calculation justifying the adequacy of the 1.83 m (6 ft) mat thickness had not been provided by Westinghouse. The following five issues remain unresolved and need to be addressed by Westinghouse:

1. In developing bounding pressure distributions for use in the foundation mat design, the soil stiffness parameters used in the analysis should be varied over a range from soft soil to hard rock in determining pressure distribution underneath the foundation mat. In addition, the variation of soil stiffness along the length of foundation mat should also be considered in the development of bounding soil pressures.

2. Since the foundation mat is only 1.83 m (6 ft) thick in the auxiliary building area, the effect of large cut-outs of pits to the overall design of foundation mat could be significant.

3. Settlements induced by the construction procedure and loads may lead to significant locked-in stresses. These settlement induced stresses (both immediate and long term) and construction loads should be included in the design of the mat foundation.

4. Because normal site investigations may overlook the local soft and/or hard spots existing in the supporting soil foundation, the effect of the possible soft/hard spots on the local soil pressure computation should be evaluated and included in the design.

5. In order to resist high shear stresses, Westinghouse applied heavy shear reinforcement in the area of auxiliary building (especially the mat foundation at the junction of the shield and auxiliary buildings). With relatively small thickness of foundation mat (the mat thickness at junction between the shielding and auxiliary buildings is 1.83 m [6 ft]), the congestion of reinforcement and deficiency of workmanship during construction at these locations may cause reduction of the shear resistance of foundation mat. Westinghouse should consider these concerns in the final foundation mat design.

D. <u>Analysis and Design of Shield Building Roof Structures</u>

From the review of the SSAR and meeting discussions with Westinghouse and its consultant, the following concerns regarding the modeling, analysis and design of shield building roof structures were raised:

1. The vertical component of the earthquake ground motion tends to increase (add to) the water pressure against the PCCS tank walls. This pressure should be considered in the design of outer tank wall and the connection between tank wall and conical roof. However, the staff found, during the meeting discussion with Westinghouse, that the design loads for the outer tank wall are very low. Westinghouse

should demonstrate and justify the adequacy of these design loads.

2. Because the slope of the conical shell is relatively shallow (35 degree), a high horizontal component of the in-plane seismic force in the conical shell due to vertical excitation of the tank under an SSE should be expected to apply at the top of the tension ring beam which supports the conical shell. This horizontal force will (1) induce high hoop stress in the tension ring beam and cause the tension ring beam to be significantly cracked, and (2) produce torsional moment on the tension ring beam and bending moment at the top of supporting columns to the tension ring beam. Westinghouse should consider these two effects in the tension ring beam design.

3. The precast panels of the shield building roof are temporarily supported on the containment vessel during construction. Westinghouse's analysis calculated the maximum reaction loads applied on the containment vessel dome and also indicated that these maximum reaction loads would be reduced as, during construction, increasing number of conical roof panels are installed, and the stiffness of the overall structure increases as each panel is erected. Westinghouse should evaluate the significance (potential of buckling) of these construction loads to the containment vessel dome.

E. <u>Design of Containment Internal Structural Modules</u>

The staff's review of Section 3.8.3 of early SSAR amendments and design calculations identified several technical concerns which require additional analysis by Westinghouse and evaluation by the staff. The focus of attention is the "M" type module which consists of two steel face plates with diaphragm plates and angle stiffeners, and is filled with lean concrete between these face plates. As described in the SSAR, composite behavior of the steel and concrete is assumed in determining structural member stiffness of the seismic model. In the design stress analysis, the loads are assumed to be primarily resisted by the steel face plates, with limited reliance on the concrete to carry a portion of design loads. The staff's concerns are (1) the assumed composite stiffness behavior needs to be verified, (2) ignorance of the composite behavior in the design stress analysis needs to be justified, and (3) the acceptable design and acceptance criteria that can be applied for the design of this type of structural elements need to be developed.

In response to these concerns, Westinghouse initiated a module behavior study of the "M" type Modules. Some preliminary design results were presented in the April 25 through 27, 1995 design review meeting. At that time, the study was still in progress. Subsequent to this meeting, Westinghouse informed the staff of its intention to significantly modify the "M" module design concept and design criteria. It is the staff's understanding that the new design will utilize an array of shear studs between the steel face plates and concrete; this modification will ensure that composite steel/concrete behavior is achieved. The design criteria will be based on the ACI 349 code for concrete; the steel face plates will be treated as reinforcing steel in meeting the code requirements. Westinghouse should complete the new design of these modules and submit the design results for the staff review.